

SCHEDULE-INDUCED DRINKING: RATE OF FOOD DELIVERY AND HERRNSTEIN'S EQUATION

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Schedule-induced drinking was measured in four rats exposed to fixed-time schedules of food ranging from 30 to 480 seconds. Herrnstein's (1970, 1974) equation relating rate of a single response as a hyperbolic function of reinforcement rate provided a good fit to three measures of drinking: lick rate, ingestion rate, and relative time spent drinking. The functions relating the three measures of drinking to reinforcement rate were of similar form. Herrnstein's equation also provided a good description of some already published data on schedule-induced drinking. The fit both to the present data and to the already published data was improved somewhat by computing the measures by subtracting from the time base a latency constant representing the minimal time required to consume the food pellet and travel to the water source. The data from this study provide two correspondences between operant behavior and schedule-induced behavior: (a) conformity to Herrnstein's equation and (b) equivalence of rate and relative time measures.

Key words: schedule-induced polydipsia, adjunctive behavior, relative time, Herrnstein's equation, fixed-time schedules, rats

Schedule-induced polydipsia, and adjunctive behavior in general, began to achieve distinction in the 1960s when physiological explanations and operant and classical conditioning explanations proved inadequate in accounting for the phenomenon (see Falk, 1969, for a review). However, subsequent investigations have shown that operant behavior and schedule-induced drinking are often similarly affected by such variables as the quality of the food substance (Falk, 1967), amount of food (Flory, 1971), and body weight (Falk, 1969). The notable exception has been the effect of the interfood interval. Whereas the rate of operant behavior varies directly with reinforcement rate,

a bitonic relationship has been obtained between polydipsic water consumption per session and the rate at which food is presented.

The bitonic function was first reported by Falk in 1966(a). He found that the volume of water consumed by rats exposed to fixed-interval (FI) schedules of food first increased with increases in FI value and then declined, generating an inverted U-shaped function between total session intake and FI value. Falk terminated each session after the delivery of a set number of pellets, arguing that since polydipsic drinking occurs immediately after food delivery, this procedure provided that "fair comparisons of water intake could be made as FI length was varied." He further argued, "Session length per se does not seem to be a major contributing factor to the results since the drinking occurs as a function of inter-pellet time, not overall session length" (1966 a, p. 39). Flory (1971) examined schedule-induced polydipsia in rats exposed to FI schedules and replicated Falk's finding of a bitonic relationship between total session water intake and FI value. Flory also terminated each session with the delivery of a set number of pellets. Hawkins, Schrot, Githens, & Everett (1972) also found the bitonic relationship when food was delivered according to variable-time (VT)

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and fixed-time (FT) food schedules and session length was determined by a set number of pellets. Hawkins et al. also found that when session length was held constant, thus allowing the number of pellets per session to vary, the water intake per pellet was a bitonic function of FI size. A similar finding was reported by Bond (1973) with various FT schedules and with session time held constant. Thus, regardless of whether the interfood interval is manipulated in the context of holding the total pellets constant or by holding the session time constant, water intake per pellet is a bitonic function of the interfood interval. Hawkins et al. were the first to point out that this seeming discrepancy between the effect of the interfood interval on schedule-induced drinking and operant behavior (i.e., bitonic vs. monotonic) arises from differences in how one measures the behavior. They showed that when the session water intake is converted to a rate measure, as is conventional with operant behavior, the resulting ingestion rate (ml/session time) is a decreasing monotonic function of the interfood interval. This finding led Hawkins et al. to conclude, "This similarity between the rate of drinking and the rate of operants on a functional level strongly suggests that the underlying processes responsible for the strength of these different behaviors are similar" (p. 103).

Other researchers have drawn similar conclusions regarding commonalities between operant and adjunctive behavior. Staddon and Simmelhag (1971) argued that the strengths of operant behavior and adjunctive behavior are directly related on the grounds that these classes of behavior are functions of the same variables. Killeen (1975) reported a quantitative formulation which relates operant and adjunctive behavior, as well as other forms of behavior, each to relative time in the interfood interval. And Herrnstein (1977) pointed out that data reported by Cohen (1975) indicated that measurement of the value of schedule-induced drinking conforms to the matching relationship describing operant choice behavior.

The present paper further explores similarities between adjunctive and operant behavior by focusing on quantification of the rate of schedule-induced drinking. Adjunctive behavior seemingly differs from operant behavior in

that the major determinant of its rate is not its consequences but rather the rate of the scheduled event which induces it, typically food. Staddon and Simmelhag's (1971) suggestion that the strength of adjunctive behavior is directly related to the strength of operant behavior suggests that mathematical formulations relating operant behavior to reinforcement rate are also applicable to schedule-induced drinking and the rate of food. Herrnstein (1970, 1974) proposed an equation in which the rate of a response is considered to be a function of the reinforcers for that response relative to all available sources of reinforcement. de Villiers (1977) and de Villiers and Herrnstein (1976) applied this equation to data from a variety of experiments where reinforcement parameters were varied and found that it provided a good description of the data. Application of the equation to schedule-induced behavior is of interest for two reasons. First, it provides another point of correspondence between schedule-induced and operant behavior. Second, the generality of Herrnstein's equation is extended to behavior which is not generally regarded as operant behavior.

In the present experiment, drinking was measured in four rats exposed to several FT food schedules. Herrnstein's equation was applied to three measures of drinking: lick rate, ingestion rate, and relative time spent drinking. The form of Herrnstein's equation applicable to single response procedures is a hyperbolic function of the form

$$R = \frac{kr}{r + r_e} \quad (1)$$

where R = rate of the measured response, r = rate of reinforcement for the measured response, r_e = all sources of reinforcement except r , and k = the maximal rate of R when r_e approaches zero with r greater than zero. In applying this formula to schedule-induced behavior, since the major determinant of its rate is the event which induces it, then r is equal to the rate of presentation of food.

Falk (1969) has argued that because "polydipsia" implies excessive fluid intake, schedule-induced polydipsia should be measured in terms of the water volume consumed. Accordingly, researchers have used this measure, or

ingestion rate, as the primary dependent measure, although licks and lick rate have also been reported. Within the context of operant behavior, it has been recognized that response rate and relative time are equivalent measures of operant behavior (Baum & Rachlin, 1969; Brownstein & Pliskoff, 1968; Premack, 1965). It is of interest, therefore, to determine if this is the case for schedule-induced drinking as well. Specifically, are lick rate, ingestion rate, and relative time spent drinking equivalent measures of schedule-induced drinking?

METHOD

Subjects

Subjects were four Holtzman male albino rats maintained at 80% of their free-feeding body weights and with free access to water. The rats were approximately 8 mo old at the start of the experiment. Their experimental histories consisted of receiving food delivered according to various FT schedules which generated schedule-induced drinking. Rat J-12 died after his sixth experimental condition, and J-11 died after his seventh experimental condition in the present study.

Apparatus

A standard, rodent operant conditioning chamber (Lehigh Valley Electronics) 23.0 cm long, 20.2 cm wide, and 19.4 cm high was used. Chamber illumination was provided by a light (#1829, 28 V) located 3.0 cm to the right of the food magazine and 6.5 cm above the grid floor. The response lever was removed.

A water bottle with a drinking spout was mounted outside the chamber on a wall adjacent to the one containing the food magazine. The spout was recessed .2 cm behind the .5-cm-thick wall. Access to the spout was provided by an aperture 1.2 cm in diameter located 6.0 cm above the grid floor and 3.3 cm from the edge of the wall adjacent to the one containing the food magazine. The shortest distance from the center of the aperture to the food magazine was 10.8 cm.

Programming and data recording were accomplished by standard electromechanical devices. Licks were counted via a Grason-Stadler drinkometer. Licks and food pellet delivery were also recorded on an event recorder. White noise masked extraneous sounds.

Procedure

Each rat was exposed to at least 6 FT schedules with intervals ranging from 15 to 480 secs. Daily experimental sessions consisted of the delivery of 41 45-mg Noyes pellets (Standard Formula A). (During the FT 480 condition, sessions for J-11 consisted of the delivery of 27 pellets.) Session lengths varied from 10.25 min at FT 15 to 5.47 hr at FT 480. Conditions were changed when there was little day-to-day variability in the number of licks per session, the number of interfood intervals containing a lick, the time between food delivery and the first lick, and the pattern of drinking within the interfood interval as indicated by event records. During the entire experiment, water was freely available at all times.

Table 1 lists the experimental conditions for each rat in the order of exposure and the number of sessions per condition. The asterisk listed by some experimental conditions indicates that an experimental manipulation, irrelevant to the present experiment, intervened between that condition and the next.

RESULTS AND DISCUSSION

All the results reported in this experiment represent the means of the last five sessions of each experimental condition.

Figure 1 shows number of licks, volume ingested, time spent drinking, and the number of interfood intervals containing at least one lick, each as a function of the FT value. All data points represent the sessions totals. For

Table 1

Order of experimental conditions and number of sessions (in parentheses) for each rat.

J-7	J-10	J-11	J-12
FT 60 (16)	*FT 240 (17)	*FT 240 (16)	FT 240 (38)
FT 120 (19)	FT 240 (39)	FT 480 (69)	FT 60 (10)
FT 240 (12)	FT 480 (47)	*FT 30 (34)	FT 30 (10)
FT 480 (10)	FT 120 (24)	FT 120 (37)	FT 480 (20)
FT 30 (21)	FT 15 (56)	FT 60 (20)	FT 120 (32)
FT 60 (32)	FT 120 (30)	FT 240 (46)	FT 15 (32)
FT 240 (52)	FT 60 (33)	FT 15 (19)	
FT 120 (28)			
FT 15 (26)			
FT 480 (29)			

*Indicates that an experimental manipulation, irrelevant to the present experiment, intervened between that condition and the next.

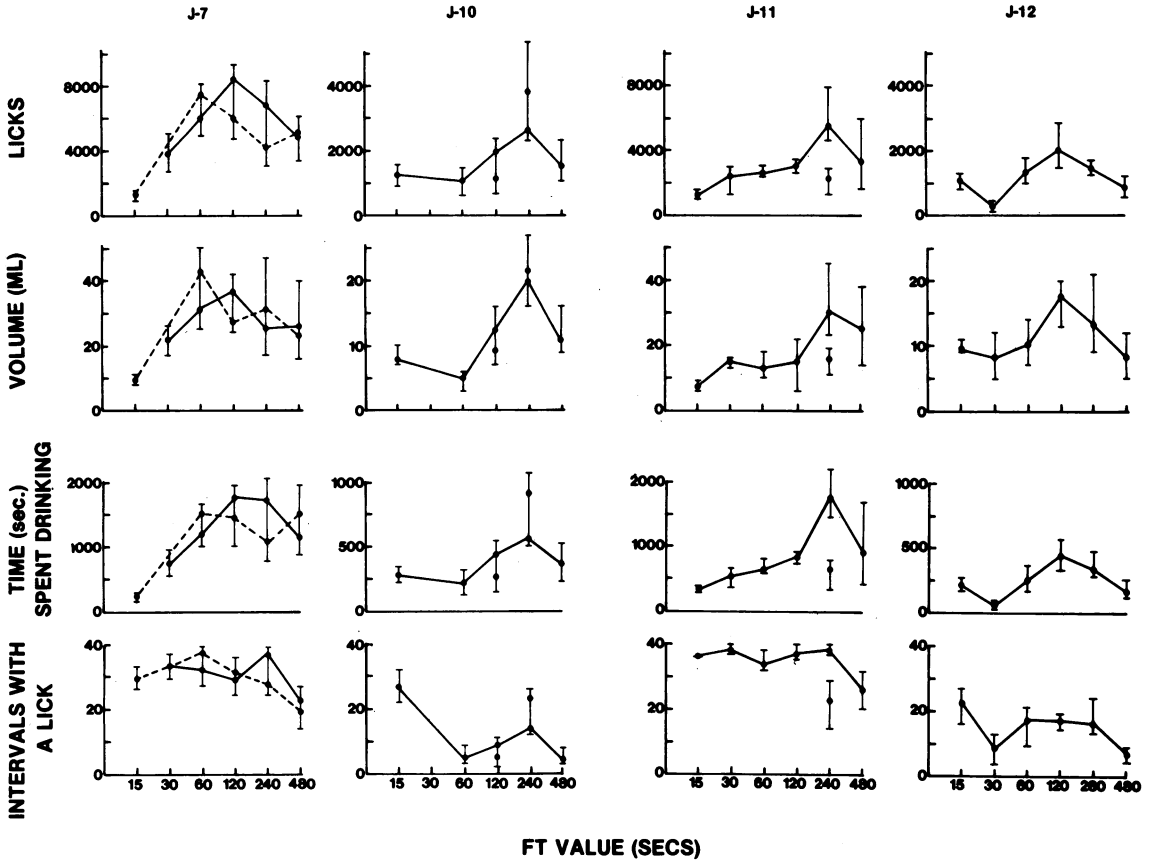


Fig. 1. Licks (top row), ml of water consumed (second row), time spent drinking (third row), and the number of intervals with a lick (bottom row), each as a function of the FT value for each rat. For rat J-7, the data points connected by solid lines represent data from the first five conditions and the data points connected by dashed lines represent data from the second five conditions.

convenience, the horizontal axis is logarithmically scaled. The vertical lines indicate the range of the data points on which the mean is based. Data from Rat J-11, given 27 pellets at FT 480, were adjusted to estimate results based on 41 pellet deliveries. Unconnected data points are redetermination values. For Rat J-7, the first five conditions (data points connected by lines) are presented separately from the last five conditions (data points connected by dashed lines). Licks, water volume, and the time spent drinking are generally inverted U-shaped functions, though there are several exceptions. For a given rat, the location of the maximal value is constant across these three measures. The number of food deliveries followed by drinking did not vary systematically as a function of the FT.

Figure 2 shows lick rate, ingestion rate, and

relative time spent drinking, each as a function of rate of food presentation. These measures were obtained by dividing the session totals presented in Figure 1 (i.e., number of licks, volume ingested, and the time spent drinking) by session time in minutes. Data from Rat J-7's first five and last five conditions are presented separately. Each graph shows a plot of the best fit of Herrnstein's equation to the data points.¹ The three numbers in each panel indicate, respectively, the values of the parameters k and r_e and the per-

¹A Burroughs 6700 calculated, to near machine accuracy, the values of k and r_e determined as the exact nonlinear least-squares fit of Herrnstein's equation by use of a variant of the Newton-Raphson method known as the modified false position method (Conte and de Boor, 1972; Hamming, 1971).

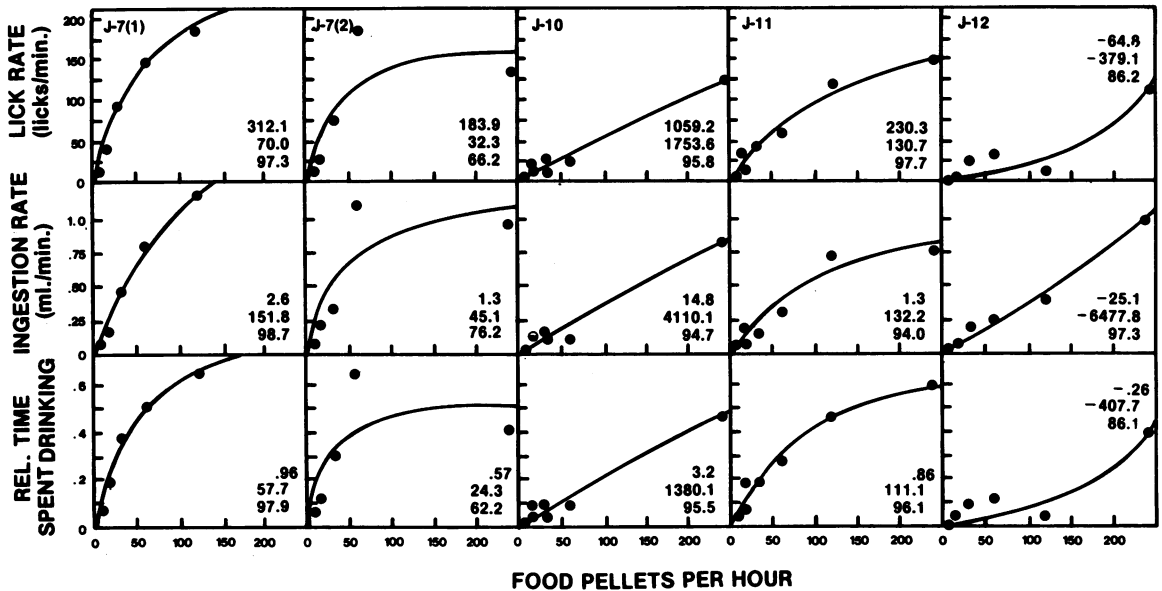


Fig. 2. Lick rate (top row), ingestion rate (middle row), and relative time spent drinking (bottom row) as a function of the rate of food presentation for each rat. The first two columns of graphs represent data from the first five and second five conditions, respectively, for Rat J-7. The smooth curves indicate the best fit of Herrnstein's equation to the data. The three numbers near each curve indicate, respectively, the k and r , values and the percentage of the variance accounted for by Herrnstein's equation. The half-shaded circle indicates overlap of first and second determination data points.

centage of the data variance accounted for by the equation. More than 94% of the data variance is accounted for in 10 of the 15 cases. Three of the five exceptions are the curves from Rat J-7's second five conditions. In these conditions, the trend of the first four data points replicates the trend of the data points in the first five conditions. But for all three measures the value at 240 pellets per hour is especially low, thus accounting for the poorer fits and for the failure to replicate the curves from the first five conditions. The other two exceptions are the curves for Rat J-12's lick rate and relative time spent drinking. All three curves for Rat J-12 have negative parameter estimates resulting in positively accelerated functions. For each rat, the three functions are of similar form suggesting an equivalence between the three measures of drinking.

In calculating the measures of strength by using the total session time base, the implicit assumption was made that all of that time was, in fact, available for drinking. However, throughout the entire experiment, the time between pellet delivery and the first lick was never as short as 1 sec for any of the rats.

Visual observation of the rats suggested that consuming the food and traveling to the drinking spout required at least 1 sec. Inasmuch as such time does not constitute functional time available for drinking, the inclusion of such time results in an underestimate of the rate and relative time measures. Let us examine how making a 1-sec latency correction affects the fit of Herrnstein's equation to the data. Table 2 shows the parameter estimates and amount of variance accounted for by fitting Herrnstein's equation to the rate and relative time measures computed by considering the FT value to be 1 sec less than the programmed value. In all 15 cases, the latency correction produced an increase in the amount of variance accounted for. The increases were not substantial. The greatest increase was 3 percentage points, and, for 10 of the 15 data sets, the increase was less than 1 percentage point. The greatest increases occurred in the five data sets for which less than 94% of the variance is accounted for without the latency correction. All of the parameter estimates are slightly increased by making the latency correction, but in most cases the curves thus generated are in-

Table 2

Parameter estimates and percentage of variance accounted for by Herrnstein's equation when a latency correction is made.

Rat	k	r_e	Percentage of variance accounted for
LICK RATE			
J-7 (1)	329.6	74.5	97.5
J-7 (2)	194.6	34.6	69.0
J-10	2866.5	4790.0	96.3
J-11	257.9	149.2	98.1
J-12	-61.6	-363.2	87.7
INGESTION RATE			
J-7 (1)	2.8	165.2	98.8
J-7 (2)	1.3	48.8	78.6
J-10	-34.4	-9689.5	95.4
J-11	1.4	148.7	94.6
J-12	-8.1	-2106.9	97.6
RELATIVE TIME			
J-7 (1)	1.0	61.4	98.1
J-7 (2)	0.60	26.0	65.2
J-10	6.6	2890.9	96.1
J-11	0.96	129.1	96.5
J-12	-0.25	-387.1	87.7

distinguishable from the curves in Figure 2. Note that for Rat J-10 both parameter estimates for ingestion rate are negative, thus generating a positively accelerated function. This outcome is related to the fact that, while the latency correction has the effect of elevating the measures at all FT values, the measures are elevated relatively more at higher reinforcement rates than at lower reinforcement rates. Thus, a function which is negatively accelerated without the latency correction can become positively accelerated when the latency correction is made. This outcome is especially likely when the value of r_e is extremely large, thus generating a curve with little curvature as in the case for J-10's ingestion rate. For Rat J-12, whose parameter estimates for the non-corrected measures were negative, the effect of the latency correction was to make the functions even more positively accelerated.

We have examined the extent to which Herrnstein's equation describes the rate and relative time measures of schedule-induced drinking obtained in the present study. Let us examine the generality of these findings to data already published. Although there are not other studies of schedule-induced drinking in rats in which licks, volume, and time

have been simultaneously measured at several interfood intervals, several studies have reported either licks or volume or both. We will examine those studies in which rate of food presentation was manipulated by simple interval schedules and in which measures of drinking could be easily derived from tables or figures. The basic procedure of the six studies meeting these criteria will be briefly described.

Bond (1973) measured water intake in 2 rats exposed to 5 FT schedules ranging from 60 to 300 sec. Burks (1970) measured both water intake and licks in 4 rats each exposed to 3 different FT schedules ranging from 8 to 72 sec. Falk (1966a) measured water intake in 2 rats exposed to 11 FI schedules ranging from 2 to 300 sec. Flory (1971) measured water intake in 3 rats exposed to 13 FI schedules ranging from 1 to 480 sec; licks were measured during 6 FT schedules ranging from 20 to 480 sec. Both water intake and licks were measured during a condition in which reinforcement consisted of the delivery of two food pellets; 6 FI schedules varying from 20 to 480 sec were presented. Hawkins et al. (1972) measured water intake in 2 rats exposed to 6 VT schedules ranging from 60 to 300 sec, 2 rats exposed to 5 FT schedules ranging from 60 to 300 sec, and 2 rats exposed to 5 FI schedules ranging from 60 to 300 sec. Keehn and Colotla (1971) examined water intake in 2 rats exposed to 5 FI schedules ranging from 15 to 300 sec.

The left-hand portion of Table 3 shows the parameter estimates and the amount of variance accounted for by the best fit of Herrnstein's equation to the data without making any correction for the initial latency. In general, Herrnstein's equation provides a very good fit to the data. In 26 of the 35 cases, more than 90% of the data variance is accounted for. The values of the parameters are fairly consistent across studies and are generally within the range found in the present study. The values of r_e for Falk's two rats are extremely large as were the values for J-10 in the present experiment. Of the 19 different rats represented, two (from Hawkins et al.) had negative parameter estimates. In the Flory study, ingestion rate in the 1-pellet condition was computed both for FIs ranging from 1 to 480 sec and 20 to 480 sec so as to allow comparison with data from the 2-pellet condition during which the FI ranged from 20 to 480

Table 3

Parameter estimates and percentage of variance accounted for by Herrnstein's equation fit to data sets from six published experiments examining schedule-induced drinking as a function of rate of food.

Experiment	No correction			Latency correction		
	k	r _e	Percentage of variance accounted for	k	r _e	Percentage of variance accounted for
<i>Bond (1973)</i>						
			ML/MIN			
Rat 1	1.2	54.3	96.2	1.3	56.6	96.3
Rat 2	2.6	211.1	97.9	2.8	228.4	98.0
<i>Burks (1970)</i>						
			ML/MIN			
Rat DB55	2.8	256.0	99.7	3.3	312.1	99.7
Rat DB56	1.6	147.5	99.8	1.7	143.7	100.0
Rat DB57	1.7	196.2	79.4	1.8	205.6	74.8
Rat DB58	1.6	322.4	99.9	2.1	458.7	100.0
			LICKS/MIN			
Rat DB55	389.7	164.3	98.7	446.0	192.6	93.0
Rat DB56	250.8	87.7	96.0	257.9	86.3	93.5
Rat DB57	226.2	46.2	92.4	243.2	45.7	81.1
Rat DB58	192.1	25.8	6.5	239.0	62.3	19.2
<i>Falk (1966a)</i>						
			ML/MIN			
Rat I-10	2.3	1140.8	95.6	-8.1	-12.0	0
Rat I-11	7.5	5246.4	98.0	-6.6	-4895.4	99.5
<i>Flory (1971)</i>						
One pellet per interval, FI = 1-480 seconds						
			ML/MIN			
Rat 2	1.6	98.0	76.6	2.4	201.5	86.9
Rat 3	2.4	194.0	62.3	2.7	179.8	81.0
Rat 4	1.3	59.3	62.8	1.5	78.8	72.7
One pellet per interval, FI = 20-480 seconds						
			ML/MIN			
Rat 2	1.7	120.8	99.0	1.8	135.7	99.1
Rat 3	1.7	99.5	98.4	1.8	111.1	98.5
Rat 4	1.4	82.1	97.5	1.5	91.2	97.7
			LICKS/MIN			
Rat 2	429.4	506.8	97.9	577.7	695.7	98.0
Rat 3	245.1	176.1	95.3	276.5	202.1	95.6
Rat 4	159.4	85.6	98.4	172.8	94.6	98.6
Two pellets per interval, FI = 20-480 seconds						
			ML/MIN			
Rat 2	1.4	55.5	94.3	1.5	60.1	94.8
Rat 3	1.5	44.0	94.1	1.6	47.6	94.7
Rat 4	.98	19.9	85.3	1.0	21.4	86.9
			LICKS/MIN			
Rat 2	189.8	132.7	98.0	209.6	148.8	98.2
Rat 3	129.2	69.6	92.4	138.4	75.4	92.9
Rat 4	130.5	30.0	97.0	130.0	32.7	97.3
<i>Hawkins et al. (1972)</i>						
VT schedules						
Rat 7A50	10.0	1109.0	90.1	13.0	1443.5	90.3
Rat 7A51	-3.4	-408.6	86.8	-3.3	-386.3	86.9
FT schedules						
Rat 8E57	5.9	542.1	97.8	7.0	643.2	97.8
Rat 8E58	-1.5	-207.4	99.0	-1.4	-200.5	99.1
FI schedules						
Rat 121	1.5	106.2	95.6	1.5	111.4	95.7
Rat 122	1.4	92.7	90.7	1.5	96.6	91.0
<i>Keehn & Colotla (1971)</i>						
			ML/MIN			
Rat S54	.63	71.3	79.7	.68	77.6	81.9
Rat S65	.91	57.8	69.3	.98	62.4	72.0

sec. Comparison reveals that the values of both k and r_e were clearly higher in the 1-pellet condition than in the 2-pellet condition. Although theoretically k should be constant (see Herrnstein, 1974), de Villiers (1977) and de Villiers and Herrnstein (1976) have also noted failures to obtain a constancy of k .

Within the 1-pellet condition of Flory's study, the ingestion rate fits were far superior when based on FIs ranging from 20 to 480 sec. This outcome suggests that a latency correction would be appropriate since the correction affects shorter FIs more than longer FIs. Because there is no empirical basis for using specific latencies, let us examine the effect of making the latency correction used in the present study. The rates from Flory's study as well as the other five studies have been recomputed by making a 1-sec latency correction. The right-hand portion of Table 3 gives the resulting parameter estimates and amount of variance accounted for. In 29 of the 35 cases, the 1-sec latency correction produced an increase in the amount of variance accounted for. In Burks' study, the latency correction produced a decrease in the percentage of variance accounted for in five of the eight cases. In Falk's study, although the correction produced an improvement in the amount of variance accounted for in one data set, for both sets the parameter estimates were negative thus producing positively accelerated functions. Note that in both cases, without the latency correction the estimates for r_e were very large, thus producing very little curvature in the function. In Flory's study, again, the value of k is higher in the 1-pellet condition. The failure of the two conditions to produce equal k values may reflect the need for different latency corrections in the two conditions. The logic of the latency correction may suggest that a larger correction should be used in the 2-pellet condition than in the 1-pellet condition. A larger correction would result in a larger k value. Similar considerations may account for several failures to obtain a constancy of k in the experiments examined by de Villiers (1977) and de Villiers and Herrnstein (1976).

An effect of the latency correction is to increase the rate and relative time measures more at the higher reinforcement rates than at the lower reinforcement rates. This outcome produces an increase in the value of

both k and r_e since k determines the asymptote of the curve and r_e affects the curvature. If the parameter estimates for the uncorrected data points are both negative, then the curve is positively accelerated and the latency correction increases the positive acceleration. If the parameter estimates for the uncorrected data points are both positive and the value of r_e is very large, the curve will be negatively accelerated with little curvature; thus, the latency correction could generate positive acceleration. Both with and without the latency correction, the present data and data already published contained several instances of large r_e values and negative parameter estimates. If one assumes that Herrnstein's equation is an acceptable description of the data, either with or without the latency correction, then the existence of large r_e values and negative parameter estimates could simply indicate random measurement error or it could indicate that rate and relative time measures at the lower reinforcement rates are underestimated. A correction in the time base which subtracted relatively more time at the lower reinforcement rates than the higher could serve to make a positively accelerated curve negatively accelerated and to increase the curvature of negatively accelerated functions.

There are some problems associated with a description of schedule-induced drinking using Herrnstein's equation. First, there is a problem in interpreting the parameter r_e . Although the primary source of control of schedule-induced drinking is intermittent food presentations, nevertheless drinking is affected by its consequences, for example, the nature of the water solution (Falk, 1966*b*; Freed, Carpenter, & Hymowitz, 1970; Keehn, Colotla, & Beaton, 1970). But in which term of Herrnstein's equation are reinforcers specific to drinking denoted? Such reinforcers may seemingly belong to r_e , which denotes all sources of reinforcement other than r . This cannot be the case, however, since the equation predicts that increasing r_e decreases R . It is apparent that, in order for Herrnstein's equation to deal with reinforcers specific to drinking, a term denoting such reinforcers must be included in both the numerator and denominator. Then r_e would denote all sources of reinforcement other than those specific to either the inducing event or the induced behavior. The fit

to the data provided by Herrnstein's equation might be improved by such considerations.

A second problem arising from describing rate of schedule-induced drinking and relative time spent drinking as hyperbolic functions of rate of food is that it is inconsistent with the finding that session totals (e.g., Figure 1) are bitonic functions. Staddon and Simmelhag (1971) have viewed this bitonic relationship as "an optimal balance between two factors: tendency to drink, which decreases as interval value increases, and time available for drinking, which increases with interval value" (p. 37). Cohen (1975) has also argued that, because ingestion rate is directly related to reinforcement rate, the bitonic function between water intake and interfood interval "is solely determined by the length of the interfood interval" (p. 43). Both of these views suggest that the bitonic function results from a combination of a decline in the rate of drinking and an increase in the time available for drinking as the interfood interval increases. But mathematically the bitonic function cannot result from these two factors if one assumes both that the time available for drinking is equivalent to (or proportional to) the time provided by the session time and that rate of drinking is a hyperbolic function of food rate. These two factors generate only monotonic functions. More explicitly, multiplying the ingestion rate values predicted by the hyperbolic fit by the corresponding session time does not produce a bitonic function. It produces another hyperbolic function (see Appendix). This problem is not necessarily insurmountable. There may be ways logically to alter the time base used to compute rate of drinking so as to generate the bitonic function. Such alterations should not necessarily be viewed as undermining the power of Herrnstein's equation, but rather as an indication that an inappropriate metric is being used in measuring the rate of behavior.

Regardless of whether Herrnstein's equation or some other model is most appropriate, the general notion of altering how response rate is computed may serve to clarify some inconsistent findings between rate of schedule-induced drinking and rate of schedule-induced escape and attack. Whereas rate of schedule-induced drinking is a monotonic function of the rate of food, both rate of attack (Cherek, Thompson, & Heistad, 1973; Cohen & Looney,

1973; Flory, 1969) and rate of escape (Brown & Flory, 1972), as well as relative time spent in attack (Flory, 1969) and relative time spent in escape (Brown & Flory, 1972) are each bitonic functions of rate of food. This discrepancy between schedule-induced drinking and schedule-induced escape and attack may be eliminated by the use of a latency correction. That is, the bitonic rate and relative time functions for schedule-induced escape and attack may be monotonic if a latency correction is made. Possibly the latency correction for these types of behavior is longer than the latency correction for drinking. This correction may reflect not only the mechanical restraints of the experimental space but also limitations imposed by the structure of behavior. For example, perhaps animals do not attack or escape for a given time after feeding. Since longer latencies result in proportionately less time available in the shorter schedules, computation of rate and relative time measures by subtracting a latency constant could generate a direct relationship between those measures and reinforcement rate.

Herrnstein's equation was initially set forth as a means of quantifying the relation between behavior and its consequences; i.e., it was a quantification of the Law of Effect (Herrnstein, 1970). Results from the present study indicate that the equation also applies to behavior which has been facilitated by operations other than manipulating its consequences. This outcome tentatively suggests the following generalization: behavior which is facilitated simply by virtue of the scheduling of some event is the same function of the rate of that event as is behavior on which the scheduled event is made contingent. Perhaps future research will show applicability of Herrnstein's equation to other types of behavior as well.

Is the case for a special class of behavior called adjunctive or schedule-induced as compelling as it was when Falk presented his initial studies in the early 1960s? One reason schedule-induced behavior was given special status apart from operant behavior was that the increase in frequency accrued to such behavior was not explicitly generated by a response-reinforcer contingency. We now know from developments in the area of autoshaping that much behavior regarded as operant also occurs in the absence of such a contingency.

Furthermore, Killeen (1975) has shown that behavior regarded as operant, respondent, schedule-induced, and general activity are similar functions of relative time in the interfood interval. He suggested that such correspondences may undermine any strong distinction between these behaviors. The present study, by showing both that schedule-induced drinking conforms to Herrnstein's equation and that rate and relative time measures are fairly equivalent, provides further support for a lack of a strong distinction between operant and schedule-induced behavior.

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APPENDIX

The fact that describing rate of schedule-induced drinking as a hyperbolic function of rate of food is inconsistent with the finding that the raw measures are bitonic functions of

rate of food can be simply demonstrated as follows. Equation 1 can be rewritten as

$$\frac{R}{T} = \frac{k \left(\frac{n}{T} \right)}{\frac{n}{T} + \frac{n_e}{T}} \quad (2)$$

where R denotes the raw measures of behavior (total session licks, total session water intake, and total session time spent drinking); T denotes the total session time; R/T denotes either lick rate, ingestion rate, or relative time spent drinking; n denotes the number of food pellets delivered; n/T denotes r from Equation 1; n_e denotes the number of sources of re-

inforcement other than food; and n_e/T denotes r_e from Equation 1. Since R is a bitonic function of rate of food, then in Equation 2 multiplication of T by the right-hand side of the equation should yield a bitonic function. Instead, the following obtains:

$$R = \frac{kn}{\frac{n}{T} + \frac{n_e}{T}} \quad (3)$$

which, by substitution, reduces to

$$R = \frac{kn}{r + r_e} \quad (4)$$

which is hyperbolic.